Nearshore Canyon Experiment: Analysis Surfzone Hole: Pilot

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LONG-TERM GOALS

The long-term goals are to understand and model the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

OBJECTIVES

The objective of the Nearshore Canyon Experiment (NCEX) is to understand the effect of complex continental-shelf bathymetry on surface gravity waves and on the breaking-wave-driven circulation onshore of the irregular bathymetry. Primary objectives this year were public distribution of the NCEX data, analysis of infragravity waves near the complex bathymetry, and investigation of wave-driven setup on different beaches. The objective of the Surfzone Hole pilot experiment was to create a large hole in the beach and observe its evolution as surfzone waves and currents transport sediment within and near the hole.

APPROACH

Our approach is to test hypotheses by comparing model predictions with waves, currents, and morphological evolution observed on natural beaches.

WORK COMPLETED

Remote sensing (microwave radar) of the nearshore was shown to produce accurate estimates of surface currents within and seaward of the surfzone (Farquharson *et al.,* 2005).

Report Documentation Page

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14. ABSTRACT
The long-term goals are to understand and model the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

15. SUBJECT TERMS

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The previously observed large directional spread of sea and swell in the surfzone was shown to result from refraction by the currents of lower frequency shear waves (Henderson *et al.*, 2006).

Models for bedload transport in two-phase sheet flow were driven with observed velocities to examine the importance of phase-lags between the bed stress and flows outside the wave boundary layer to swashzone sediment transport (Hsu and Raubenheimer, *2006*). Simplified models were used to test parameterizations for sediment transport, and compared with observed sandbar migration (Hsu *et al., 2006*).

The loss of infragravity wave (periods of a few minutes) energy observed in the surfzone was shown to be the result on nonlinear interactions with higher frequency swell (Thomson *et al.,* 2006, Henderson *et al., in press*), explaining the tidal modulation of infragravity motions observed in bottom seismic records on the continental shelf (Thomson *et al.,* 2006).

Including the effect of bottom stress leads to improved skill in models that predict wave-induced setup, especially near the shoreline. The effects of rollers on setup were shown to be small (Apotsos *et al.*, in press).

As part of NCEX, over 100 sensors were deployed offshore, near, and onshore of two submarine canyons (Figure 1). In addition, bathymetric surveys extending from above the shoreline to about 8-m water depth were conducted almost weekly along several km of the coast. The data were made available to the public on the WWW (http://science.whoi.edu/users/elgar/NCEX).
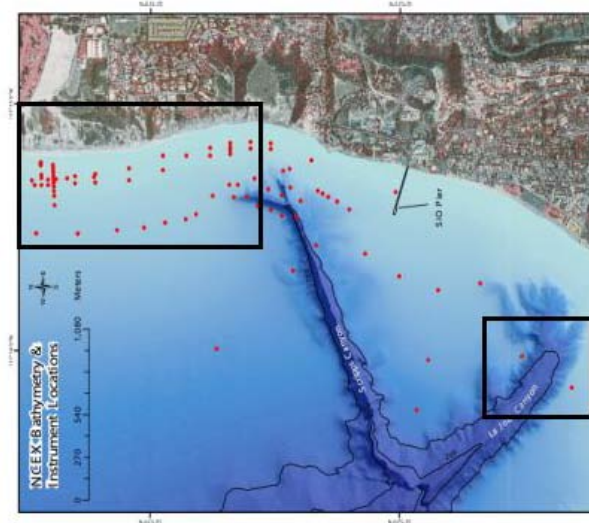

Figure 1. The NCEX instrument array (red circles) and bathymetry (contours are m relative to mean sea level). The black boxes indicate the instruments used for the studies of infragravity wave reflection (box on right side) and energy loss (box on left side). [Instruments were deployed at over 100 locations offshore, near, and onshore of two submarine canyons that extend from deep water almost to the shoreline.]

In Fall 2005 we determined that we can create a 10-m diameter, 2-m deep hole near the shoreline at low tide (Figure 2), and that we can instrument it rapidly so that currents can be measured when the tide rises and waves cover the hole.

Figure 2. [Overhead photograph of a 10-m diameter, 2-m deep hole created with heavy equipment near the low-tide shoreline. Ten sensors with colocated pressure gages and current meters (white cylinders) were used to measure flows and waves in and offshore of the hole at mid to high tide levels. The surrounding sand levels were surveyed continuously as the hole filled in with sediment.]

RESULTS

Infragravity waves near submarine canyons:

The observed reflection of ocean surface gravity waves with periods between 20 and 200 s from the steep-walled La Jolla submarine canyon is consistent with long-wave theory (Thomson *et al.,* 2005), allowing wave propagation models to be extended to include the strong effects of canyon reflections. For example, the theory accurately predicts that as much as 60% of the energy of waves approaching the canyon normal to its axis is reflected. Although waves approaching the canyon at oblique angles cannot propagate over the canyon, total reflection was observed only at frequencies higher than about 20 mHz, with lower frequency energy partially transmitted across, analogous to the quantum tunneling of a free particle through a classically impenetrable barrier. During the 4-week observational period, on average more than half the incident infragravity wave energy was reflected by La Jolla submarine canyon, showing that reflection contributes significantly to the near-canyon infragravity wave energy balance.

Infragravity energy levels observed in bottom-pressure records and seismic sensors deployed on the continental shelf are strongly modulated at tidal periods. Recently graduated MIT-WHOI Joint Program student Dr. Jim Thomson used observations from NCEX to demonstrate that the observed tidal modulations of infragravity energy are caused by differences in nonlinear interactions between these low frequency long waves and higher frequency swell in the surfzone as the beach slope changes

with the rising and falling tide. In particular, on many beaches the low tide beach profile is convex (red profile in Figure 3, lower) and the high tide profile is concave (blue profile, Figure 3, lower), and thus waves are in shallow water over a longer distance at low tide than at high tide (Thomson *et al*. 2006). Nonlinear interactions that transfer energy from long waves to swell are stronger in shallow water, and thus more energy is transferred at low (red circles, Figure 3, upper) than at high (blue squares, Figure 3) tide. The energy transfer results in an apparent dissipation (changes in energy flux are negative, Figure 3) of the low frequency long waves. The tidal difference in energy transfer causes there to be less energy available to reflect from the shoreline at low tide, and thus offshore energy levels change with the tide. The discovery that the observed energy loss is the result of nonlinear interactions, rather than owing to dissipative processes, such as turbulence generation, is a new finding (Thomson *et al.,* 2006, Henderson *et al.* 2006).
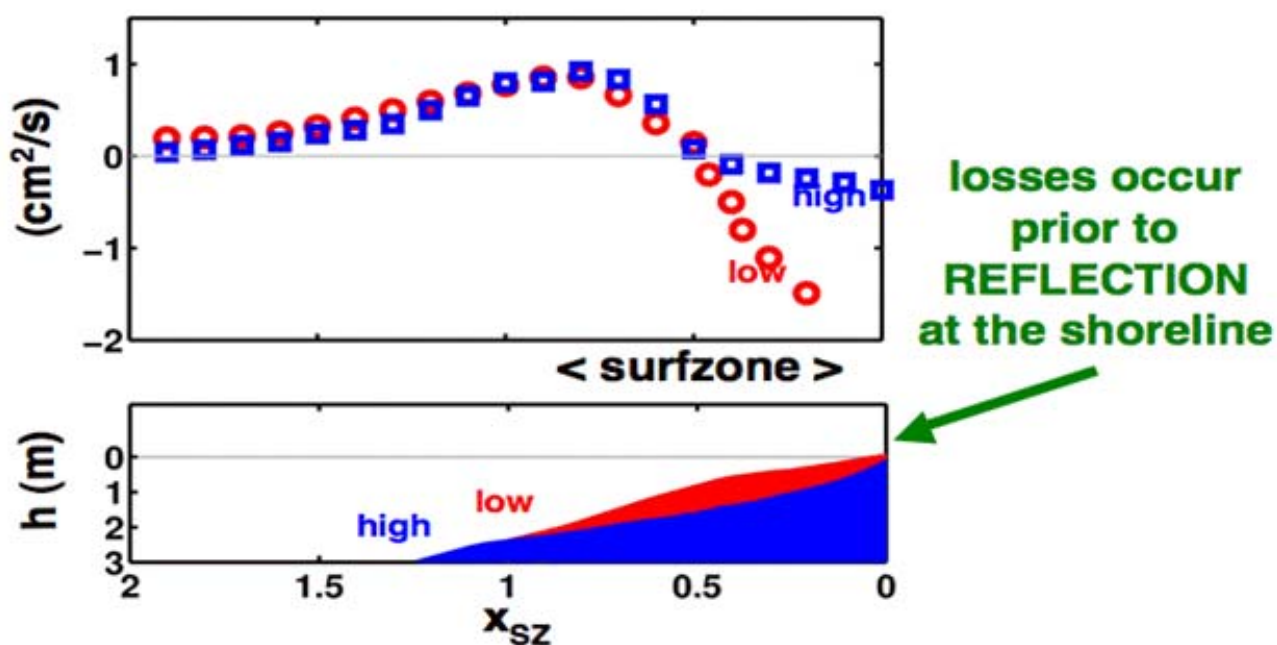

Figure 3. (Upper) Energy transfer rate and (lower) water depth versus distance from the shoreline normalized such that a distance of 0 corresponds to the shoreline and a distance of 1 corresponds to the seaward edge of the surfzone. Nonlinear interactions transfer energy from swell to infragravity waves seaward of the surfzone infragravity (symbols in upper panel). In contrast, nonlinear interactions transfer energy from infragravity waves to swell inside the surfzone zone, especially over the convex-shaped low-tide beach profile. [The red circles in the upper panel show that in the surfzone there is significantly more energy transfer away from infragravity waves over the convex-shaped low-tide beach profile than over the concave-shaped high-tide profile.]

The new information about infragravity waves can be incorporated into regional models that simulate the wave field over the complex canyon bathymetry. Standard ray-tracing techniques based on Snell's law can be used to track the paths of waves as they refract over the complex bathymetry. When the rays intersect a canyon, the results found in this study can be used to determine how much energy is reflected and how much is transmitted across the canyons, as well as the changes in direction experienced by both reflected and transmitted waves. An example of ray paths that include both refraction and reflection is shown in Figure 4. In this example, infragravity waves are reflected at the

shoreline, and propagate toward deeper water with initial angles and energy levels based on observations. As the waves travel over the complex bathymetry, they refract (black curves in Figure 4) until they reach a canyon, where some energy is reflected (red curves) and some is transmitted (blue curves). The reflected and transmitted components continue to refract over the bathymetry.
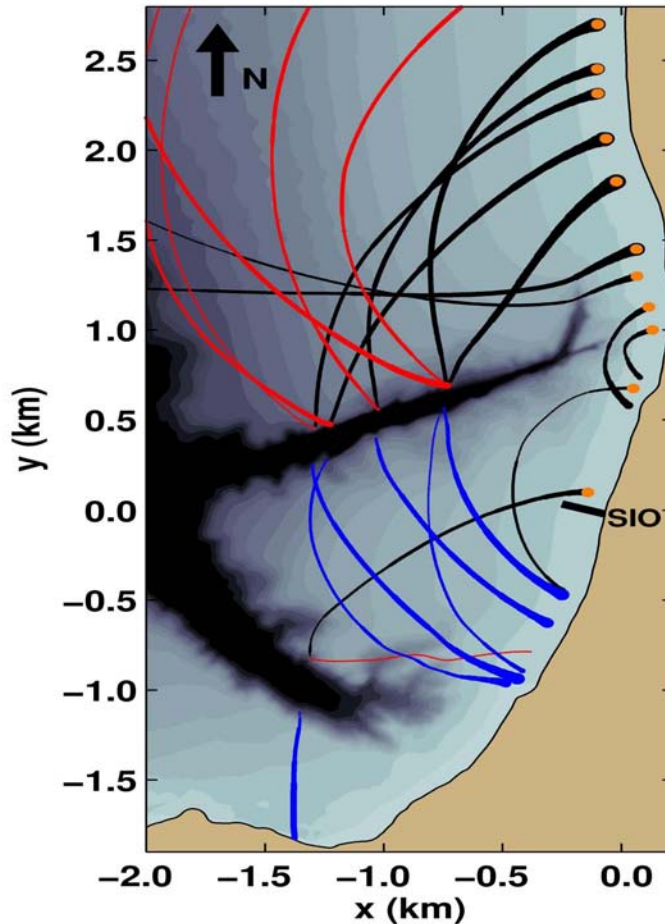

Figure 4: Ray paths accounting for refraction (black curves), reflection (red), and transmission (blue). The rays are initialized near the shoreline (orange circles at the termination of the black curves) with energy and direction based on observations. The thickness of the curves is proportional to the energy flux. [A map of the offshore bathymetry showing the two steep submarine canyons that extend close to the shoreline. Ray paths of waves refracting and reflecting are shown as curves that become thinner in deeper water because the waves are conserving energy flux. Rays that intersect a canyon are divided into a reflected and a transmitted component, both of which then continue to propagate according to Snell's law until they reach the beach or travel offshore of the area shown.]

Including the effects of reflection from the canyons leads to significantly improved model skill, especially near the canyons (Figure 5). Although far from a canyon, refraction-only models predict the observed wave energy accurately (Figure 5, right), in the shadow of Scripps Submarine Canyon (Figure 5, left) models that do not account for canyon reflections overpredict the observed wave energy significantly.
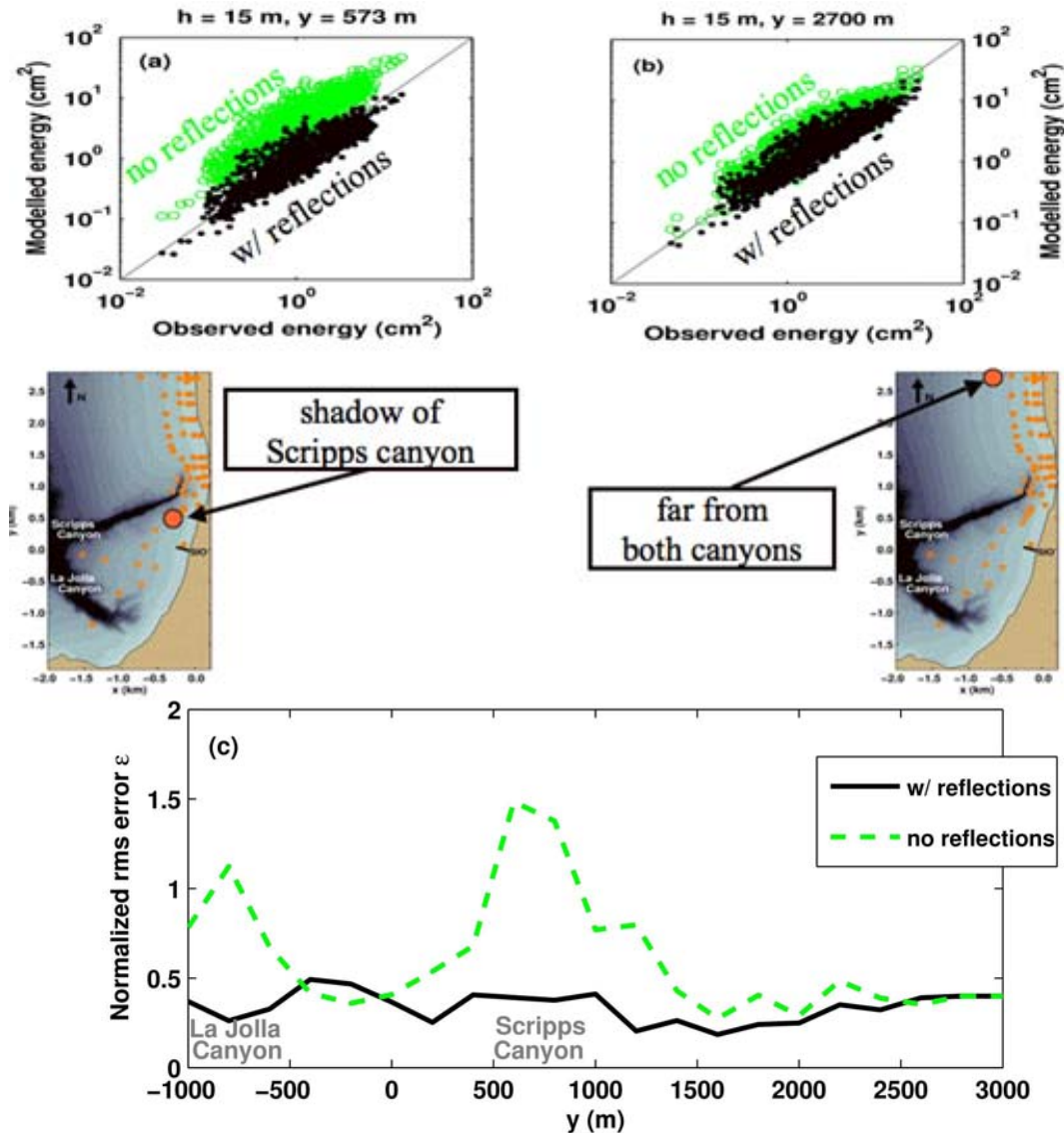
Figure 5. Modeled versus observed infragravity energy (a) near and (b) far from a canyon. Observations were obtained near the large circles shown on the maps below each scatter plot. (c) Root-mean-square error between model predictions and observations of infragravity energy versus alongshore location for models with (black solid curve) and without (green dashed curve) canyon reflections. [Near a canyon, the model without accounting for reflections overpredicts the observed infragravity energy by a factor of about 10, whereas the model that accounts for reflections is accurate. Far from the canyons, both models (with and without reflections) are accurate. The rms errors for the model without reflections increase as much as 300% close to the canyons, whereas the errors for the model with reflections are nearly constant across the domain.]

Evolution of a hole near the shoreline:

To investigate the coupling and feedback between waves, currents, sediment transport, and morphological evolution in the nearshore, 10-m diameter, 2-m deep holes were made with excavation equipment near the low-tide water line. Several of the holes were instrumented (Figure 2) with current

meters and pressure gages. The bathymetry near and within the hole was surveyed before excavation, and continuously as the tide rose and water covered the hole. Dye was released upstream and within the hole to visualize flow patterns with video.

As water reached the hole, waves and currents produced rapid sediment transport and changes to the morphology. The offshore edge of the initially circular hole eroded rapidly, providing a path for water to exit the hole (Figure 6). As the tide rose, more waves covered the hole and the neighboring beach, resulting in a widening gap at the offshore edge, with the initially circular hole becoming semi-circular, and eventually filling completely. After a few hours, the hole was almost gone, and by the next low tide there was no obvious sign of the hole (Figure 7).
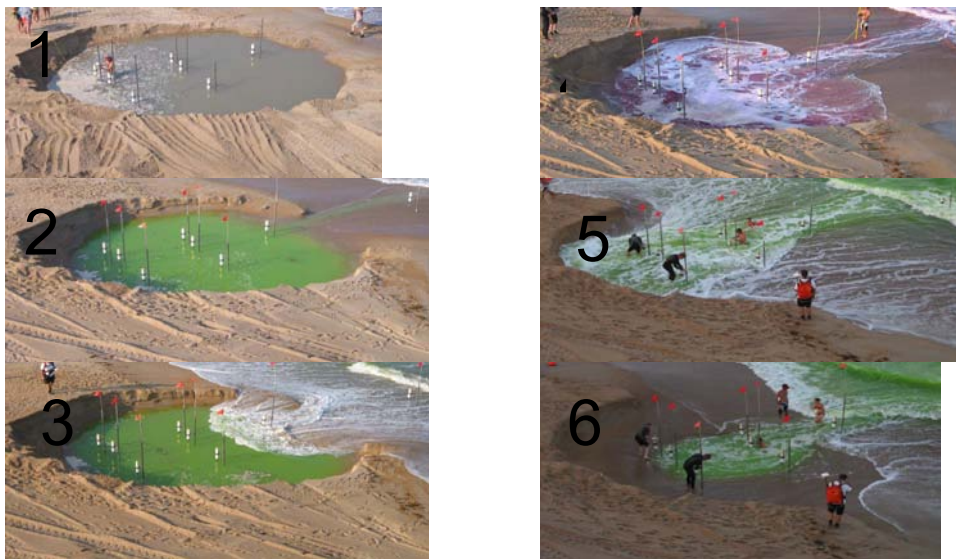

Figure 6. Photographs of a hole as it evolves from its initial configuration (upper left). Time increases from upper left to lower left, then from upper right to lower right. Dye shows the flow patterns as waves run up into the hole, and strong flows leave the center of the depression. [The initially round, 10-m diameter, 2-m deep hole evolved to a semi-circular shape, and then was filled nearly completely.]
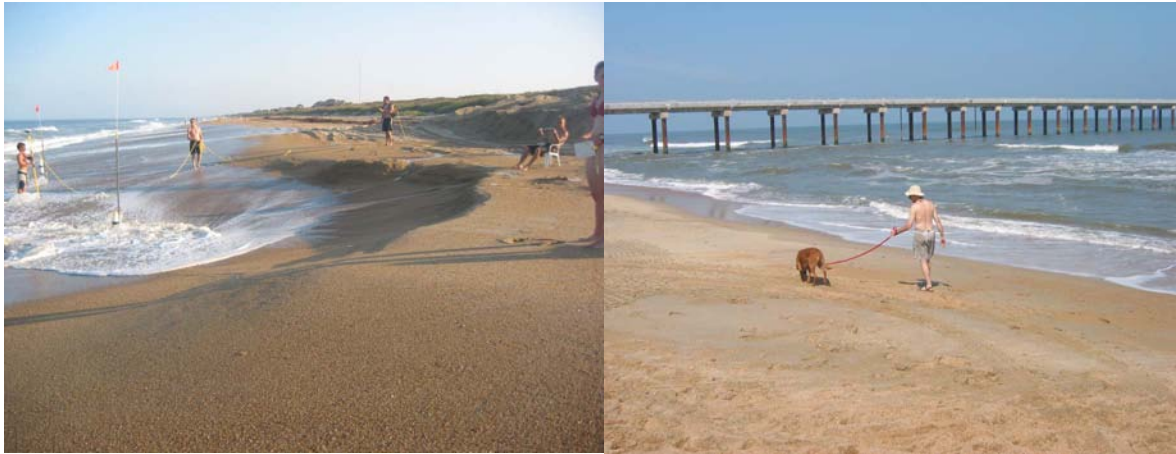
Figure 7. [Photographs of the remains of the hole (left) 3 hours after waves started to reach it, and (right) the next day after a tidal cycle (almost all traces of the hole have vanished).]

IMPACT/APPLICATIONS

The field observations have been used to verify and improve models for nearshore and surfzone waves, circulation, and morphological change, and to ground truth remote sensing techniques to estimate nearshore currents. The comparison of model predictions with observations has increased our ability to predict nearshore bathymetric change, including the migration of sandbars across the surfzone.

It has been shown that we can create a large perturbation (eg, a hole) to the nearshore bathymetry and instrument it before the tide rises and waves, currents, and sediment transport begin to change the morphology.

RELATED PROJECTS

The Duck94 and SandyDuck observations are being used to test components of the NOPP nearshore community model, as well as other models (eg, DELFT3D) for nearshore waves, currents, and bathymetry.

The studies of nearshore waves, currents, and morphology are in collaboration with NSF projects funding swashzone research, numerical modeling, and undergraduate fellows.

Studies of surfzone circulation and mixing using drifters and current meters deployed during NCEX are in collaboration with a California Sea Grant project.

Observations of nearshore bedforms are being used as part of Mine Burial Program studies (with E. Gallagher).

NCEX observations are being used in collaboration with modeling studies and as ground truth for remote sensing of nearshore waves and currents. More than 20 researchers (from US universities, Navy laboratories, and American engineering companies, as well as from European institutions) have downloaded data from the NCEX data distribution site in 2006.

REFERENCES

Apotsos, Alex, Britt Raubenheimer, Steve Elgar, R.T. Guza, and Jerry Smith, The effects of wave rollers and bottom stress on setup, *J. Geophysical Research,* **in press**.

Farquharson, G., S. Frasier, B. Raubenheimer, and S. Elgar, 2005 Microwave radar cross sections and Doppler velocities measured from the surf zone, *J. Geophys. Res.,* **110**, doi:1029/2005JC003022 .

Henderson, S., R.T. Guza, S. Elgar, and T.H.C. Herbers, 2006 Refraction of surface gravity waves by shear waves, *J. Phys. Oceanog.,* **36**, 629-635.

Henderson, Stephen, R.T. Guza, Steve Elgar, T.H.C. Herbers, and A.J. Bowen, Nonlinear generation and loss of infragravity wave energy, *J. Geophysical Research,* **in press**.

Hsu, T.-J., and B. Raubenheimer, 2006 A numerical and field study on inner-surf and swash sediment transport, *Cont. Shelf. Res***, 26,** 589-598.

Hsu, T.-J., S. Elgar, and R.T. Guza, 2006 A wave-resolving approach to modeling onshore sandbar migration, *Coastal Engr.,* **53,** 817-824.

Thomson, J., S. Elgar, and T. H. C. Herbers, 2005 Reflection and tunneling of ocean waves observed at a submarine canyon, *Geophys. Res. Lett.,* **32**, L10602, doi:10.1029/2005GL022834.

Thomson, Jim, Steve Elgar, T.H.C. Herbers, Britt Raubenheimer, and R.T. Guza, 2006 Tidal modulation of infragravity waves via nonlinear energy losses in the surfzone, *Geophysical Research Letters* **33,** L05601, doi:10.1029/2005GL025514.

PUBLICATIONS

Apotsos, Alex, Britt Raubenheimer, Steve Elgar, R.T. Guza, and Jerry Smith, The effects of wave rollers and bottom stress on setup, *J. Geophysical Research,* **in press**. [published, in press, refereed]

Farquharson, G., S. Frasier, B. Raubenheimer, and S. Elgar, 2005 Microwave radar cross sections and Doppler velocities measured from the surf zone, *J. Geophys. Res.,* **110**, doi:1029/2005JC003022. [published, refereed]

Henderson, S., R.T. Guza, S. Elgar, and T.H.C. Herbers, 2006 Refraction of surface gravity waves by shear waves, *J. Phys. Oceanog.,* **36**, 629-635. [published, refereed]

Henderson, Stephen, R.T. Guza, Steve Elgar, T.H.C. Herbers, and A.J. Bowen, Nonlinear generation and loss of infragravity wave energy, *J. Geophysical Research,* **in press.** [published, in press, refereed]

Hsu, T.-J., and B. Raubenheimer, 2006 A numerical and field study on inner-surf and swash sediment transport, *Cont. Shelf. Res.***, 26,** 589-598. [published, refereed]

Hsu, T.-J., S. Elgar, and R.T. Guza, 2006 A wave-resolving approach to modeling onshore sandbar migration, *Coastal Engr.,* **53,** 817-824. [published, refereed]

Spydell, Matthew, Falk Feddersen, R.T. Guza, and W. Schmidt, Observing Surfzone Dispersion with Drifters, *J. Phys. Ocean*, submitted. [submitted, refereed].

Schmidt, W. E., R.T. Guza, and D.L. Slinn, 2005 Surfzone currents over irregular bathymetry: drifter observations and numerical simulations, *J. Geophys. Res*. **110**, C12015, doi:10.1029/2004JC002421. [published, refereed]

Thomson, Jim, Steve Elgar, T.H.C. Herbers, Britt Raubenheimer, and R.T. Guza, 2006 Tidal modulation of infragravity waves via nonlinear energy losses in the surfzone, *Geophysical Research Letters* **33,** L05601, doi:10.1029/2005GL025514. [published, refereed]